

**USING GIS TO MODEL RESOURCE SELECTION AND HABITAT  
SUITABILITY OF THE AFRICAN FOREST ELEPHANT  
IN THE CONGO BASIN**

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## ABSTRACT

A Geographic Information System (GIS) is a useful tool for analyzing resource selection of wildlife species and predicting and mapping habitat suitability. This study combined telemetry data from thirty forest elephants in central Africa with spatially explicit environmental covariates to understand forest elephant resource selection and habitat preference using an autologistic generalized linear model (GLM). Resource selection among the collared elephants was similar in that across all sub-regions they selected for proximity to one or all ecological features including mineral holes (bais), non-navigable rivers and wetlands. The collared elephants also actively avoided at least one source of human threat including settlements, roads, and navigable rivers in four out of the five sub-regions.

The African forest elephant (*Loxodonta africana cyclotis*), which comprises one-quarter to one-third of the world's remaining African elephant populations, has not been studied until more recently and remains poorly understood. Resource selection analyses such as the one conducted in this study could help with planning of proper conservation corridors for safe migration and dispersal of forest elephants, especially as threats from human pressure in the Congo Basin increase in the future.

In addition, a GIS was used to construct an expert-based habitat suitability map for the forest elephant across the Congo Basin using a spatial model approach developed by the Wildlife Conservation Society's (WCS) Living Landscapes Program. The map integrates spatial information on biological habitat requirements of the species with information on severity of human threats. This is the first time such a map has been created for the Congo Basin and can serve as a useful tool for determining future forest elephant conservation prioritization in this region.

## 1. Introduction

Forest elephants (*Loxodonta africana cyclotis*) make up one-quarter to one-third of the world's remaining African elephants (Eggert et al. 2003). At moderate densities, forest elephants comprise the largest contribution to mammalian biomass in Africa's tropical forests in West and Central Africa (White 1994). These animals are known as a *keystone species*, dispersing seeds for many plants and trees and therefore contributing to the health and regeneration of forest environments (Chapman et al. 1992, White et al. 1993, Blake 2002). Forest elephants also create and maintain forest clearings, known in Central Africa as *bais*, which are used by other animals to obtain mineral salts (Ruggiero and Fay 1994). In comparison to savanna elephants (*Loxodonta africana africana*), forest elephants have been not been studied until more recently and still remain poorly understood (Barnes et al. 1995). The primary reason for this is because their habitat in dense remote rain forests makes them difficult to study and observe in comparison to the high visibility inherent in savanna elephants' open grassland habitats (White et al. 1993, Thurow 2002). It has been speculated that forest elephants might constitute a sub-species or even a distinct species of African elephant (Roca et al. 2001). Considerable progress toward understanding the ecology of forest elephants has been made in recent decades, but this knowledge is still in its early stages and there is still much to be learned about its habitat preference and geographic distribution.

In the forests of the Congo Basin in Central Africa, forest elephants are threatened by mounting pressure from humans (Walsh et al. 2003; Wilkie et al. 2001) and their numbers are in decline (Blake et al. 2007). Pressures include a variety of

human factors, including habitat fragmentation from logging (Perez et al. 2005) and road construction (Wilkie et al. 2001; Trombulak and Frissel 2000) as well as illegal poaching and hunting for ivory (Fa et al. 2002; Fa et al. 2003; Blake et al. 2007). Even in National Parks, where these animals should be relatively safe from humans, forest elephant populations are threatened by increased levels of poaching due to demand for ivory and bushmeat (Blake et al. 2007). Road construction by logging companies in more remote forests of Central Africa enables poaching to be present in areas which would otherwise be inaccessible to humans.

The future of forest elephant populations in Central Africa remains extremely uncertain today. Stepping up efforts to protect and conserve this vital species, therefore, is of greatest urgency. Increasing our knowledge of forest elephant habitat selection and predicting their geographic distribution in Central African forests using spatially explicit information and maps created by a Geographic Information System (GIS) is one step toward aiding in their conservation. To that aim, this analysis examines environmental factors contributing to forest elephant habitat preference and uses a modeling approach to create a prediction map of elephant suitability in the Congo Basin. It is hoped that this paper will aid in geographic targeting of conservation strategies for protection of forest elephants and for biodiversity in the Congo Basin in general.

## 2. Background

### **2.1 Forest elephant resource selection in Central Africa**

Forest elephant resource selection has not previously been studied using GPS telemetry data in Central Africa. However, certain habitat studies have been conducted examining forest elephant dung density in the region.

Barnes et al. (1997) found that dung density of forest elephants in Gabon increased with distance from roads and villages, and that overall elephant density in Gabon was related inversely to human activity. The study also found that forest elephants showed a preference for selectively logged forests, as well as abandoned logging roads within concessions. Blom et al. (2004) found that forest elephant dung density increased dramatically with greater than 10 kilometer distances from roads. In addition, a survey of six sites in the Congo Basin conducted by the Monitoring of the Illegal Killing of Elephants (MIKE) program found that forest elephant abundance decreased with distances from roads even in remote national parks and other protected areas (Blake 2005). As for specific habitat preference, Blake and Inkamba-Nkulu (2004) found that trail networks and fruit trees, mineral holes called *bais* and stands of Marantacee forest (open canopy forest with very dense herbaceous understory) are preferred by forest elephants and can also partly determine their ranging patterns. White (1994) also found seasonal fruit availability to be a strong driver of forest elephant movement. Most recently, Blake et al. (2007) found patterns of road avoidance in forest elephants consistent with previous studies from dung surveys conducted in several parks in Central Africa during 2003-2005. The study also found

that distance from the nearest road was a strong predictor of forest elephant abundance, human presence and poaching.

## **2.2 Resource selection analyses and species distribution models: The GLM method**

Understanding how wildlife use surrounding habitats is of paramount importance to ecology and species management (McClellan et al. 1998, Boyce and McDonald 1999). Habitat selection studies usually compare assessments of habitat use to habitat availability, showing how animals actively select the environments where they spend most of their time (Manly et al. 1993).

Resource selection and species distribution models can be used to analyze intensity of resource use and predict the geographical distribution of a particular species by combining information from point occurrence data and environmental variables (Boyce et al. 2002, Graham and Hijmans 2006). A variety of statistical approaches can be used. Many studies have utilized generalized linear models (GLMs) for modeling wildlife distributions (Walker 1990, Osborne and Tigar 1992, Buckland and Elston 1993). A GLM provides a method to estimate a function of the mean response of a dependent variable as a linear combination of a set of predictors (Insightful Corporation 2001). GLMs are particularly useful for species distribution modeling because they provide a solid statistical foundation for realistically modeling ecological relationships (Austin 2002). Using this method, a study region is divided into grid cells and data on abundance or presence/absence is tabulated for each cell. The spatial distribution of a species within the grid can then be determined by relating the response variable (abundance or presence/absence of each grid cell) to spatially

referenced covariates (Augustin et al. 1996, Boyce et al. 2002). A Poisson regression utilizes abundance or count data as the dependant variable (Insightful Corporation 2001). It belongs to a family of the GLM and was used in this study to examine the response of forest elephant telemetry hit abundance to a set of covariate predictors. It is important to note that this model will be used not as a prediction model, but as a means to explore relationships between telemetry fix abundance and a set of covariates.

### **2.3 Mapping habitat suitability: The WCS Living Landscapes approach**

An expert-oriented map of forest elephant habitat suitability in the Congo Basin will be created by combining spatially explicit information on forest elephant habitat and human threat factors which exert pressure on forest elephants in the basin. Such a map of forest elephant habitat suitability and associated threats has not been created for the Congo Basin before. A conservation modeling approach developed by the Wildlife Conservation Society's (WCS) Living Landscapes Program (WCS 2005) will be utilized in creating the map.

The model approach, developed as part of the WCS Landscape Scale Approach (LSA), aims to provide a GIS-based method to model and predict habitat suitability for wide-ranging species. The components of the model include deriving a "Biological Landscape" layer, which takes into account biological covariates thought to influence a particular species' habitat and a "Human Landscape" layer, which takes into account human covariates which might exert significant pressure on, or pose certain threats to, the species' habitat. Both Biological and Human Landscape layer model inputs are based on expert opinion of known information about the species'

biological preferences and relationships to human factors. The model approach combines both landscape layers to create a “Conservation Landscape” layer, or habitat suitability surface, for the species. This resulting layer, as well as each Biological and Human Landscape layer is a spatial raster GIS dataset which features a gradient scale of habitat suitability for the species (Strindberg et al. 2004, WCS 2005).

### 3. Data

#### **3.1 Study Area**

The equatorial forest of Central Africa, which stretches from the west coast of Gabon to the eastern border of Democratic Republic of Congo (DRC), comprises the second largest area of rain forest in the world after South America's Amazon forests. Extending almost 2 million square kilometers, it contains the forested regions of the Congo Basin and serves as important habitat for a unique assemblage of invertebrates and large terrestrial mammals including the forest elephant. As it is noted for being among the least impacted and most “wild” regions containing perhaps the highest biological diversity of Africa (Sanderson et al. 2002), the conservation value of the Congo Basin is enormous. Its large tracts of intact forest make it important to consider its conservation value as essential forest elephant habitat. **Figure 1** shows a map of the region. This analysis will examine forest elephant habitat selection in five sub-regions within the Congo Basin. The five sub-regions are, from east to west: 1) areas within the Gamba Complex between Loango National Park and Moukalaba-Doudou National

Park, 2) areas within Lope National Park, 3) areas within Ivindo National Park, 4) areas within Odzala National Park, and 5) areas within Nouabale-Ndoki National Park.

### **3.2 Elephant telemetry data**

The Wildlife Conservation Society (WCS) has coordinated a region-wide study of forest elephant ranging behavior through the use of GPS telemetry in the Congo Basin. Thirty forest elephants were immobilized and collared with GPS telemetry units in the five sub-regions in Gabon and Republic of the Congo between 2000 and 2005 (Figure 1). Most of the telemetry collars functioned for over 1 year with the data reaching, or closely approximating, asymptote for elephant home range size.

Certain sources of error exist within the GPS telemetry data. One caveat of the data is that GPS “fix” schedules were not standardized, and the data vary from hourly to 24-hour periodicity. To overcome this bias, all data were sampled to include only one fix per day in the habitat analysis.

Another caveat of the telemetry data is that many data points are missing due to failure of satellite fix acquisitions. Fix acquisition failure can be caused by many factors such as canopy cover, terrain, and forest type (Cain III et al. 2005, Friar et al. 2004). It is important to note that the resulting bias is not random, especially in areas such as the Congo Basin where thick canopy cover is often a problem. Therefore, it is prudent to state that this particular forest elephant GPS telemetry data is highly biased toward open habitats.

A third bias inherent in the elephant telemetry data is due to where the elephants were collared. Most were collared inside National Parks in relatively

remote locations, and their habitat selection and use of space is constrained within these areas. While some elephants did wander outside of parks, most stayed within park boundaries. Therefore this data is not necessarily representative of how forest elephants use space across the entire Congo Basin, especially outside of National Parks.

#### 4. Methods

##### **4.1 Resource selection analysis using a GLM approach**

The following three sections detail the methods and steps taken to conduct the resource selection analysis.

###### **4.1.1 Data preparation: Assembling the telemetry and covariate data**

First, the telemetry data were standardized by randomly selecting one point per day to remove the bias caused by non-standardized fix schedules. This process was completed using a customized macro in Excel. Minimum convex polygons (MCPs) were then generated to delineate the spatial extent of each elephants' individual range. This was done using a tool available in *Hawthorne's Analysis Tools* extension for ArcMap ([www.spatialecology.com](http://www.spatialecology.com)). The MCP method is widely used in wildlife studies to assess home ranges of animals and is particularly applicable for use with telemetry data, as it takes into account all areas where the animal is recorded (Leggett 2006). The telemetry datasets for each individual elephant were then converted to grids of 1 kilometer resolution and the number of telemetry fix points contained within each grid cell was calculated. Each grid was then clipped to the extent of each MCP.

The following environmental covariates were used in the habitat selection analysis for each sub-region: landcover type, distances inside and outside National Parks, distances to National Park headquarters, slope, distances to bays, distances to wetlands, distances to non-navigable rivers, distances to navigable rivers (accessible by humans), distances to roads, distances to human settlements, and presence of logging concessions. All covariate data are in ESRI GIS Grid format, projected to World Sinusoidal equal-area projection, with a grid cell resolution of 1kilometer. All covariates are listed with corresponding sources in **Table 1**. All variables were continuous except landcover type and presence of logging concessions, which were categorical. All distance grids were created using the “Find Distance” tool in ESRI ArcGIS software.

As a final step, each grid containing abundance and absence data within each elephant’s MCP was spatially intersected with each environmental covariate to obtain a spreadsheet with associated covariate data for each record. The output spreadsheets were merged into a final datasheet with a unique ID assigned to each elephant within each individual sub-region.

#### **4.1.2 Spatial autocorrelation**

In order to understand the amount of spatial autocorrelation inherent in the telemetry data, variograms were run using the statistical software package R. Lack of independence in telemetry data increases the probability of a Type I error by inflating the degrees of freedom (Legendre 1993). As animals typically move non-randomly,

telemetry datasets are frequently autocorrelated, which follows the reasoning that if one grid cell is occupied, then neighboring cells are more likely to also be occupied.

A method to explicitly model the effects of spatial autocorrelation in the GLM analysis was used. This procedure, called an autologistic model, is explained in Augustin et al. (1996). It extends the original logistic GLM model to include the occupancy responses from neighboring grid cells as a covariate. This method has been found to be especially effective in estimating the spatial distribution of animals based on abundance or presence/absence data (Augustin et al. 1996). To derive this covariate for the autologistic model, the sum of all count grid cells within five kilometers was calculated for each cell using R software. The resulting variable was called D5.

#### **4.1.3 Running the autologistic generalized linear model**

Using R statistical software, a number of stepwise Poisson GLM regressions were run to determine covariate use intensity by each elephant within each sub-region. The dependent variable consisted of a count of the number of telemetry hits per 1 kilometer grid cell within each elephant's home range MCP. A map of the range of each elephant and its proximity to each covariate was examined. Covariates which did not seem to visually impact an elephants' range were eliminated. Also eliminated were certain covariates where elephants did not venture closer than approximately 50 kilometers to the feature. The reasoning behind this elimination was based on expert knowledge of elephant behavior provided by Dr. Stephen Blake and the scale by which forest elephants make ranging decisions. For certain

elephants, ANOVA (Analysis of Variance) tests were conducted to determine the most important variables determining an elephant's intensity of use.

#### **4.2 Developing a spatial model of forest elephant suitability using the Conservation Landscape approach**

For preparation of the Conservation Landscape model inputs, selected environmental covariate layers were sub-divided into two categories of Biological Landscape covariates and Human Landscape covariates. The source information and expected impact on forest elephant habitat suitability of each spatial GIS layer used in the analysis is shown in **Table 2**. All country-level data were merged by theme to create consistent thematic datasets extending over the entire Congo Basin. Each layer was projected into Sinusoidal equal-area projection. Biological covariates consisted of a ranked surface of landcover type and wetlands. Distances to baiss were not used because a layer covering the entire basin is not available. Human Landscape covariates included distances to navigable rivers, distances to roads, distances to human settlements, distances to human refugee camps, and presence of logging concessions.

All layers contributing to the Biological Landscape input of the model were ranked on a scale of 1-100 for forest elephant habitat suitability, with 100 indicating high suitability and 0 indicating non-suitability. Areas of mature and degraded forests were ranked 100. Wetlands were also ranked 100 and a conditional statement was created to merge the layers. Ranking decisions were based on forest elephant literature and expert guidance from WCS forest elephant researcher, Dr. Stephen Blake.

The layers contributing to the Human Landscape input of the model were ranked on a scale of 1-100, with class 100 representing high human threat and class 0 representing no human threat. Each distance layer was re-classed into ten classes and ranked and weighted according to the logic that grid cells in closest proximity to these particular centers or axes of human threat received higher threat to forest elephant habitat. Again, ranking decisions were based on forest elephant literature, knowledge of human and wildlife relationships in the Congo Basin, and expert guidance provided by Dr. Stephen Blake. For the final step of creating the Conservation Landscape layer, the Biological and Human Landscape layers were mathematically added together to create unique combinations of habitat quality and threat level.

## 5. Results

### **5.1 Forest elephant resource selection: GLM response to covariates**

Determining actual forest elephant resource selection from the stepwise GLM models proved to be more problematic than anticipated because certain covariates exhibited non-linear relationships in their response to the telemetry data. A logarithmic scale was applied in certain cases to understand whether particular statistical relationships improved, but this was not effective for every covariate. Certain covariates, such as distances to roads and human settlements, were statistically fit to a 2<sup>nd</sup> order polynomial, but because the ecological significance was debatable given the objectives of the analysis, this idea was not pursued further.

After running stepwise GLM Poisson models for each individual elephant, the resulting coefficients for each covariate response were transferred to a table grouped

by sub-region. Significance ( $p$ -value < 0.05) of each response was also specified. The results of each sub-region are described below.

**Sub-region 1: Loango National Park and Gamba Complex.** Results of coefficient relationships and significance of covariates for each elephant in this sub-region are shown in **Table 3**. Ten elephants were sampled. This particular sub-region is unique in that it is a coastal environment, and eight out of ten of the collared elephants spent all of their time among the marshes and beaches along the coast. An explanation for this is partly due to where the elephants were first collared. The GLM results show this habitat preference: In seven of the elephants, distance to wetlands was a significant predictor, and six coefficients showed preference for nearness to wetlands. Landcover type 4, which characterized coastal beaches, was significant and positive for three of the ten elephants. The distance to non-navigable rivers covariate was significant in seven out of the ten collared elephants but showed mixed relationships. Three coefficients were negative, showing forest elephant preference, and four were positive, showing avoidance. This might be due to the fact that this particular group of collared elephants preferred to be closer to the ocean than to rivers. Human threat covariates showed different relationships from what was expected because of the nature of the coastal environment and could not be interpreted easily. For example, for elephants where distances to roads was a significant predictor, all coefficients were negative, showing preference. However, it could be argued that this relationship is unavoidable because many roads have been built up and down the coast, and even extend into Loango Park, running directly through the center of a good number of collared elephants' home ranges. The same is

true for human settlements. For the six elephants where distance to settlements was a significant predictor, three elephants spent time closer to settlements and three avoided them.

**Sub-region 2: Lope National Park.** Results of coefficient relationships and significance of covariates for each elephant in this sub-region are shown in Table 3. Four elephants were sampled in this sub-region, and each elephant stayed confined inside the park boundaries. All of the elephants preferred less steep slopes. There were no wetlands in this sub-region. Two of the collared elephants preferred proximity to non-navigable rivers and simultaneously avoided proximity to navigable rivers, showing possible aversion to human activity. Distance to National Park headquarters was significant for three of the collared elephants, and all three exhibited avoidance of this covariate. Preference for grassland landcover type 4 was also significant for all elephants. Distance to roads was a significant predictor for all elephants and equal numbers showed preference and avoidance. Two elephants also showed preference for proximity to human settlements near the border of the park.

**Sub-region 3: Ivindo National Park.** Results of coefficient relationships and significance of covariates for each elephant in this sub-region are shown in Table 3. Four elephants were sampled in this sub-region and some wandered outside the park boundaries. The distance to non-navigable rivers covariate was significant for three out of four elephants, and all relationships showed preference. The same was true for distances to navigable rivers. Of the three elephants where the distance to wetlands covariate was significant, two showed preference. Logging concessions were favored by two of the forest elephants who wandered outside the park (logging concessions

surround these areas of the park). Of the two elephants where distance to human settlements was significant, half showed avoidance and half showed preference.

There were no roads in this sub-region.

**Sub-region 4: Odzala National Park.** Results of coefficient relationships and significance of covariates for each elephant in this sub-region are shown in Table 3. Five elephants were sampled in this park and only one wandered outside the park boundary. This area is known for its Marantacee forest, which is most likely not fully represented by the coarse nature of the landcover covariate. The distance to bais covariate was significant for four of the collared elephants, and showed equal preference and avoidance. The distance to non-navigable rivers covariate was significant for all five elephants, and three elephants showed preference. Distances to National Park headquarters were significant for only two elephants, and both showed preference. Coefficients for distance to roads were significant for four out of the five collared elephants, and three elephants exhibited avoidance. Two of the collared elephants showed preference for areas closer to human settlements, but it is likely that the presence of bais in the same area affected this relationship.

**Sub-region 5: Noubale-Ndoki National Park.** Results of coefficient relationships and significance of covariates for each elephant in this sub-region are shown in Table 3. Seven elephants were sampled in this park and six of them spent time outside the park boundary. A reason for this could be due to the abundance of bais and wetlands located south and southeast of the park where the six elephants wandered. Both distances to bais and distances to non-navigable rivers were significant predictors of elephant resource selection in six out of the seven collared

elephants. However, only three of the elephants showed preference for proximity to bais while four of the five elephants showed preference for proximity to non-navigable rivers. An ANOVA test showed that the distance to bais covariate was the most important factor influencing the models for four elephants. Distance to National Park headquarters was a significant predictor for four of the seven elephants. Of these, three elephants avoided the headquarters and one preferred closer proximity. Logging concessions also were a significant predictor of three elephants who favored them. It was not clear from the analysis of this sub-region how forest elephants responded to human threat covariates. Because roads and settlements are abundant south and southeast of the park where the bais and wetlands are located, the response coefficients for these human covariates showed habitat preference for roads and equal preference and avoidance of human settlements. The significance of these covariates was generally low in comparison to the biological covariates, however.

## **5.2 Forest elephant suitability map of the Congo Basin**

The resulting forest elephant suitability map for the Congo Basin derived from the WCS Living Landscapes approach is shown in **Figure 2**. It is important to note that the map categories do not directly translate to a linear gradient of forest elephant habitat suitability so each category must be assessed individually in terms of its biological suitability score and corresponding human threat score (for example, biological suitability = low, threat level= high). National Parks have been overlaid on the map for reference. It is interesting to note that although National Parks were not used as a model input, the modeled output areas which comprise the majority of the

parks have been categorized as having low human threat. National Parks encompassing areas categorized as having medium threat are mostly located in the Democratic Republic of Congo and in coastal areas of Gabon.

## 6. Conclusions

Additional studies which seek to understand resource selection of the forest elephant at fine scales are crucial to developing a foundation for determining appropriate management and conservation strategies for this species. In every sub-region studied, the collared forest elephants preferred proximity to one or many ecological features present in the Congo Basin including bays, non-navigable rivers, and wetlands. Certain collared elephants also preferred areas inside logging concessions. It is important to note that in many cases, logging concessions can be dangerous habitat for forest elephants. Visibility of elephants is higher in cleared areas, and elephant populations within concessions are more vulnerable to poaching by loggers and locals who use newly-built logging roads to gain access to these areas. Logging companies, especially those owning concessions adjacent to National Park boundaries, should take initiative to provide their loggers with incentives which discourage hunting for bushmeat and illegal wildlife products such as ivory in order to protect forest elephant populations utilizing these open habitats.

As human activities taking place within the Congo Basin increasingly threaten forest elephant habitat, proper intervention is increasingly time-sensitive and urgent. In four out of the five sub-regions, forest elephants actively avoided at least one human presence covariate (proximity to settlements, roads, and/or navigable rivers).

Fragmentation and human disturbance of forest elephant habitat will have serious consequences for the genetic structure of forest elephant populations as they become isolated and contained within protected areas and smaller regions within the Congo Basin. Resource selection studies such as this could help with planning proper conservation corridors for the safe migration and dispersal of forest elephants.

According to the derived Conservation Landscape map for forest elephant habitat suitability in the Congo Basin, additional opportunities to protect forest elephants do exist in this broad region. **Figure 3** highlights these areas with circles. The map shows a significant portion of southeastern Cameroon designated as high habitat suitability with low human threat. It would be ideal to focus forest elephant conservation efforts in this area and perhaps create an extended cross-border transnational park connecting Ivindo N.P. in northern Gabon to this area in southeastern Cameroon. It is important to note that circled areas designated as high suitability in northern Republic of Congo (east of Noubale-Ndoki National Park) are currently designated as logging concessions. Because poaching levels within logging concessions in Central Africa are often especially high, conservation attention should be brought to these areas, recognizing them as potential forest elephant habitat. The circled area in central Republic of Congo, south of Lac-Telé, represents the heart of a vast wetland. This area will be least likely to suffer great amounts of human pressure because it is largely inaccessible. In DRC, two areas exist in the northern part of the country which could be considered for forest elephant conservation. However, due to current political instability in DRC it might not be feasible that such a process could be undertaken at this time.

## 7. Discussion and Considerations for Future Work

### **7.1 Resource selection of the forest elephant in Central Africa**

GIS proved to be an extremely useful tool for elucidating relationships between forest elephant telemetry fix abundance and several biological and human threat covariates. Certain considerations should be followed for future work.

One fundamental problem with the results of the analysis overall was that many covariate responses to the telemetry data were non-linear. A logarithmic scale was applied to see if statistical relationships improved, but this was not always effective and the biological relevance was questionable. Some statistical relationships improved with the use of mixed models and fitting certain covariates (such as distances to rivers and human settlements, for example) to a 2<sup>nd</sup> order polynomial. This step was eliminated in the current analysis, however, because more time must be given to assessing the ecological significance of using mixed models and polynomials for analyzing particular covariates. An alternative route might be to explore the use of generalized additive models (GAMs), which have also been found to be useful and sometimes more flexible for ecological modeling.

Scale plays a significant role in the manner in which forest elephants select their habitats and resources. Senft et al. (1987) and Boyce et al. (2003) found that because resource distribution, foraging costs and threats vary with scale, animals may pursue different resources at large and small spatial scales. This finding is certainly applicable in the case of this analysis, especially at a 1kilometer resolution. A decision for an elephant to head toward a river might be based on that elephant being 500 meters to 1 kilometer away from the river, but a decision for an elephant to avoid

a human settlement might be based on a distance of ten kilometers. These relationships are still being understood by ecologists and this issue must be addressed for future work.

In some cases, the spatial covariate data used in the analysis was lacking and could have contributed particular sources of error to the results. Distinguishing between navigable and non-navigable rivers, for example, proved difficult. Navigable rivers were defined as main (Level 1) rivers. Non-navigable rivers were defined as smaller tributaries which were assumed to be less accessible by humans. It is likely, however, that many of these smaller rivers also serve as points of human activity. Data showing locations of bais was also lacking, as it was only available for two sub-regions. It is possible that bais are a significant component of elephant resource selection in other sub-regions.

The telemetry data contained many biases (explained in Section 5.2) which could have contributed to certain problems in the analysis. Efforts were made to standardize fix schedules with a macro which deleted all extraneous telemetry hits except for one random telemetry fix per day. This introduced certain bias into the data, as the macro could theoretically produce a different set of data with subsequent runs. In addition, it greatly reduced the number of samples for certain elephants whose collar batteries failed earlier than anticipated. This was the case for approximately four elephants in the sampled pool—they did not have sufficient data to produce meaningful results. Other biases explained in the above section, such as problems with fix acquisition and biases due to where the elephants were collared, were not addressed in this analysis and could be examined in future work.

## **7.2 Modeling forest elephant suitability in the Congo Basin**

Maps showing habitat suitability and species distribution can provide a strong foundation for applied research and conservation planning (Graham and Hijmans 2006). These maps are only as effective as the data and methods used to create them, however. A major challenge in undertaking any type of modeling effort exists in overcoming problems and challenges relating to the quality and type of data used for the suitability model. Overcoming data shortages and limitations proved to be a particular challenge – for example, forest elephants prefer to spend large amounts of time in and near baobabs in the forests of Central Africa. Unfortunately, there is no comprehensive dataset of locations of baobabs for the entire region so the model excluded this important influence on forest elephant habitat.

Another challenge in creating the suitability model lies in the fact that it is very hard to take into account contextual characteristics of the landscape, such as prevalence of safari hunting or strife caused by social or military conflict across the entire Congo Basin. Due to political instability in the Democratic Republic of Congo, for example, availability of spatial data which might be able to accurately capture the extent of human pressure on forest elephant habitat throughout the country has not been collected. In addition, all logging concessions in the country have been designated inactive and therefore do not have associated spatial data. Due to high levels of corruption within the country, however, it is likely that certain areas of the country are experiencing deforestation and human encroachment. These instances as well as others cannot always be captured and reflected in the coarse-scale model.

The WCS Living Landscapes modeling approach has certain advantages and disadvantages. As with all expert models, the model depends on multiple iterations of revisions and “fine-tuning” based on a) trial and error and b) expert opinion by biologists and wildlife ecology experts who are familiar with the biological habitat selection of forest elephants. It is important to note that WCS recommends that both the Biological and Human Landscape layers should be considered working hypotheses which should be improved and revised as new data layers become available and as knowledge of covariate layer relationships relating to the species’ habitat suitability is enhanced.

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## References

- Augustin, N.H., Muggleston, M.A., and Buckland, S.T. 1996. "An autologistic model for the spatial distribution of wildlife." *Journal of Applied Ecology* 33:339-347.
- Austin, M.P. 2002. "Spatial prediction of species distribution: an interface between ecological theory and statistical modelling." *Ecological Modelling* 157:101-118.
- Barnes, R. F. W., A. Blom, and M. P. T. Alers. 1995. "A review of the status of forest elephants *Loxodonta africana* in Central Africa." *Biological Conservation* 71:125-132.
- Barnes, R. F. W., K. Beardsley, F. Michelmore, K. L. Barnes, M. P. T. Alers, and A. Blom. 1997. "Estimating forest elephant numbers with dung counts and a geographic information system." *Journal of Wildlife Management* 61:1384-1393.
- Blake, S. 2002. *The Ecology of Forest Elephant Distribution and its Implications for Conservation*. P.h.D. Dissertation thesis, University of Edinburgh, Edinburgh.
- Blake, S., and Inkamba-Nkulu, C. 2004. "Fruit, minerals, and forest elephant trails: Do all roads lead to Rome?" *Biotropica* 36:392-401.
- Blake, S. 2005. *Long Term System for Monitoring the Illegal Killing of Elephants (MIKE) in Central African Forests: Final Report On Population Surveys (2003 - 2004)*. 122 pages. The Wildlife Conservation Society. Bronx, NY: WCS.
- Blake, S., Strindberg, S., Boudjan, P., Makombo, C., Bila-Isia, I., Ilambu, O., Grossmann, F., Bene-Bene, L., de Semboli, B., Mbenzo, V., S'hwa, D., Bayogo, R., Williamson, L., Fay, M., Hart, J., and Maisels, F. 2007. "Forest elephant crisis in the Congo Basin." *PLoS Biol* 5(4): e111. doi:10.1371/journal.pbio.0050111.
- Blom, A., van Zalinge, R., Mbea, E., Heitkonig, I.M.A., and Prins, H.H.T. 2004. "Human impact on wildlife populations within a protected Central African forest." *Afr. J. Ecol.* 42:23-31.
- Boyce, M. and L. McDonald. 1999. "Relating populations to habitats using resource selection function." *Trends in Ecology and Evolution* 14:268-272.
- Boyce, Mark S., Vernier, Pierre R., Nielsen, Scott E., and Schmiegelow, Fiona K.A. 2002. "Evaluating resource selection functions." *Ecological Modeling* 157:281-300.
- Boyce, Mark S. et al. 2003. "Scale and heterogeneity in habitat selection by elk in Yellowstone National Park." *Ecoscience* 10:421-431.
- Buckland, S.T. and Elston, D.A. 1993. "Empirical models for the spatial distribution of wildlife." *Journal of Applied Ecology* 30:478-495.
- Cain III, James W., Krausman, Paul R., Jansen, Brian D., and Morgart, John R. 2005. "Influence of topography and GPS fix interval on GPS collar performance." *Wildlife Society Bulletin* 33:926-934.

Chapman, L.J., Chapman, C.A, and Wrangham, R.W. 1992. "Balanites wilsoniana: elephant dependent dispersal?" *Journal of Tropical Ecology* 8:275-283.

Congo Basin Forest Partnership (CBFP). 2005. *The Forests of the Congo Basin: A Preliminary Assessment*. Available online at:  
[http://carpe.umd.edu/products/PDF\\_Files/FOCB\\_APrelimAssess.pdf](http://carpe.umd.edu/products/PDF_Files/FOCB_APrelimAssess.pdf)

Fa, J. E., Peres, C. A. and Meeuwig, J.. 2002. "Bushmeat exploitation in tropical forests: An intercontinental comparison." *Conservation Biology* 16:232-237.

Fa, J. E., Currie, D. and Meeuwig, J. 2003. "Bushmeat and food security in the Congo Basin: Linkages between wildlife and people's future." *Environmental Conservation* 30: 71-78.

Friar, J.L., S.E. Nielsen, E.H. Merrill, S.R. Lele, M.S. Boyce, R.H.M Munro, G.B. Stenhouse, and H.L. Beyer. 2004. "Removing GPS collar bias in habitat selection studies." *J. of Applied Ecol.* 41: 201-212.

Graham, Catherine H. and Hijmans, Robert J. 2006. "A comparison of methods for mapping species ranges and species richness." *Global Ecol. Biogeogr.* 15:578-587.

Insightful Corporation. 2001. *S-PLUS 6 for Windows Guide to Statistics, Volume 1*.  
Insightful  
Corporation, Seattle, WA.

Legendre, P. 1993. "Spatial autocorrelation: trouble or new paradigm?" *Ecology* 74:1659-1673.

Leggett, Keith E.A. 2006. "Home range and seasonal movement of elephants in the Kunene Region, northwestern Namibia." *African Zoology* 31:17-36

Manly, B.F.J., McDonald, L.L., and Thomas, D.L. 1993. *Resource Selection by Animals. Statistical Design and Analysis for Field Studies*. Chapman and Hall, London, UK.

McClellan, S.A., Rumble, Mark A., King, Rudy M., and Baker, William L. 1998. "Evaluation of resource selection methods with different definitions of availability." *Journal of Wildlife Management* 62:793-801.

Osborne, P.E. and Tigar, B.J. 1992. "Interpreting bird atlas data using logistic models : an example from Lesotho, Southern Africa." *Journal of Applied Ecology* 29:55-62.

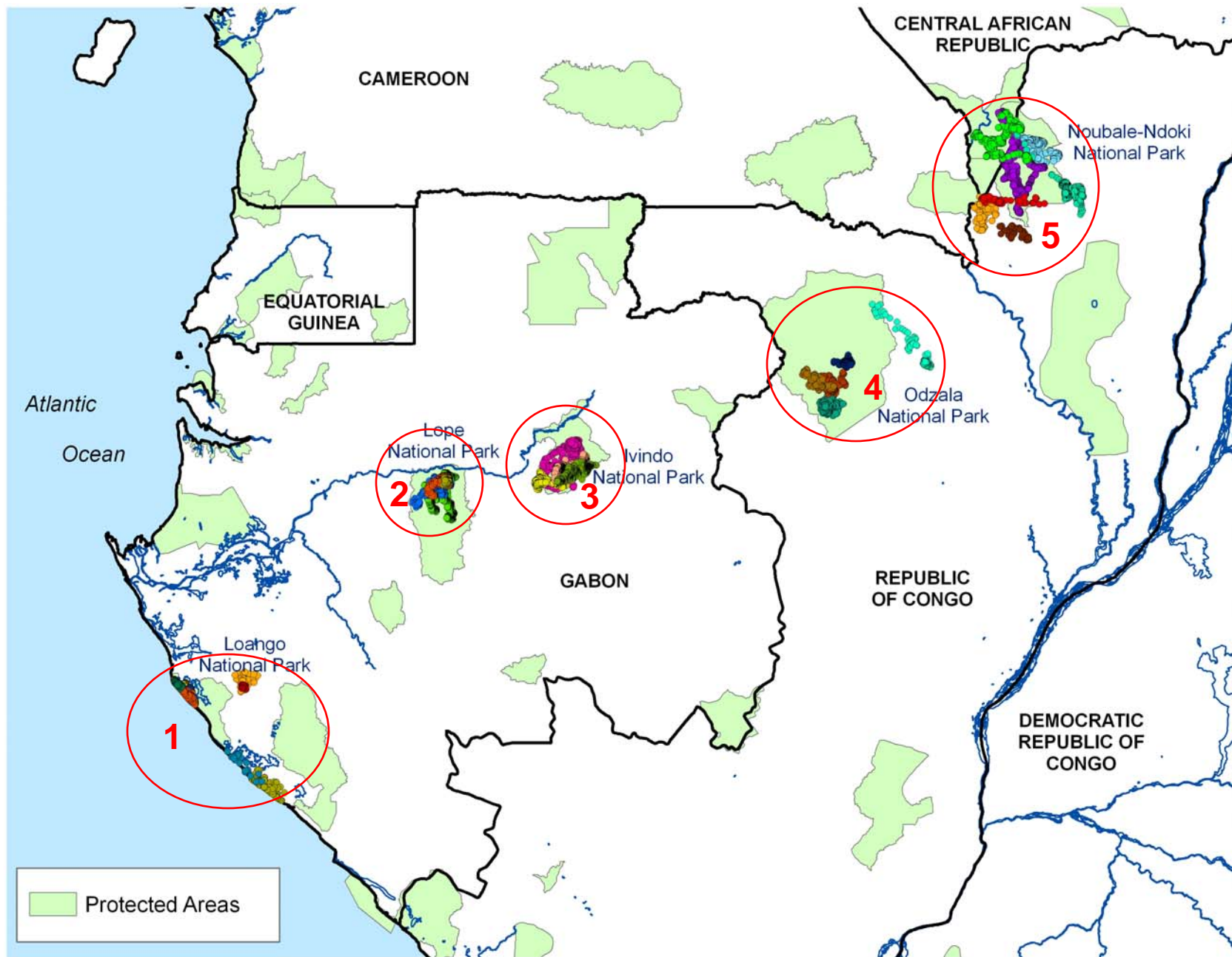
Perez, M. R., de Blas, D. E., Nasi, R., Sayer, J. A., Sassen, M., Angoue, C., Gami, N., Ndoye, O., Ngono, G., Nguinguiri, J. C., Nzala, D., Toirambe, B., Yalibanda, Y. 2005. Logging in the Congo Basin: A multi-country characterization of timber companies. *Forest Ecology and Management* 214: 221-236.

Roca, A.L., Georgiadis, N., Pecon-Slattery, J., and O'Brien, S.J. 2001. "Genetic evidence for two species of elephant in Africa." *Science* 293:1473-1477.

Ruggiero, R.G. and Fay, J.M. 1994. "Utilization of termitarium soils by elephants and its ecological implications." *African Journal of Ecology* 32:222-232.

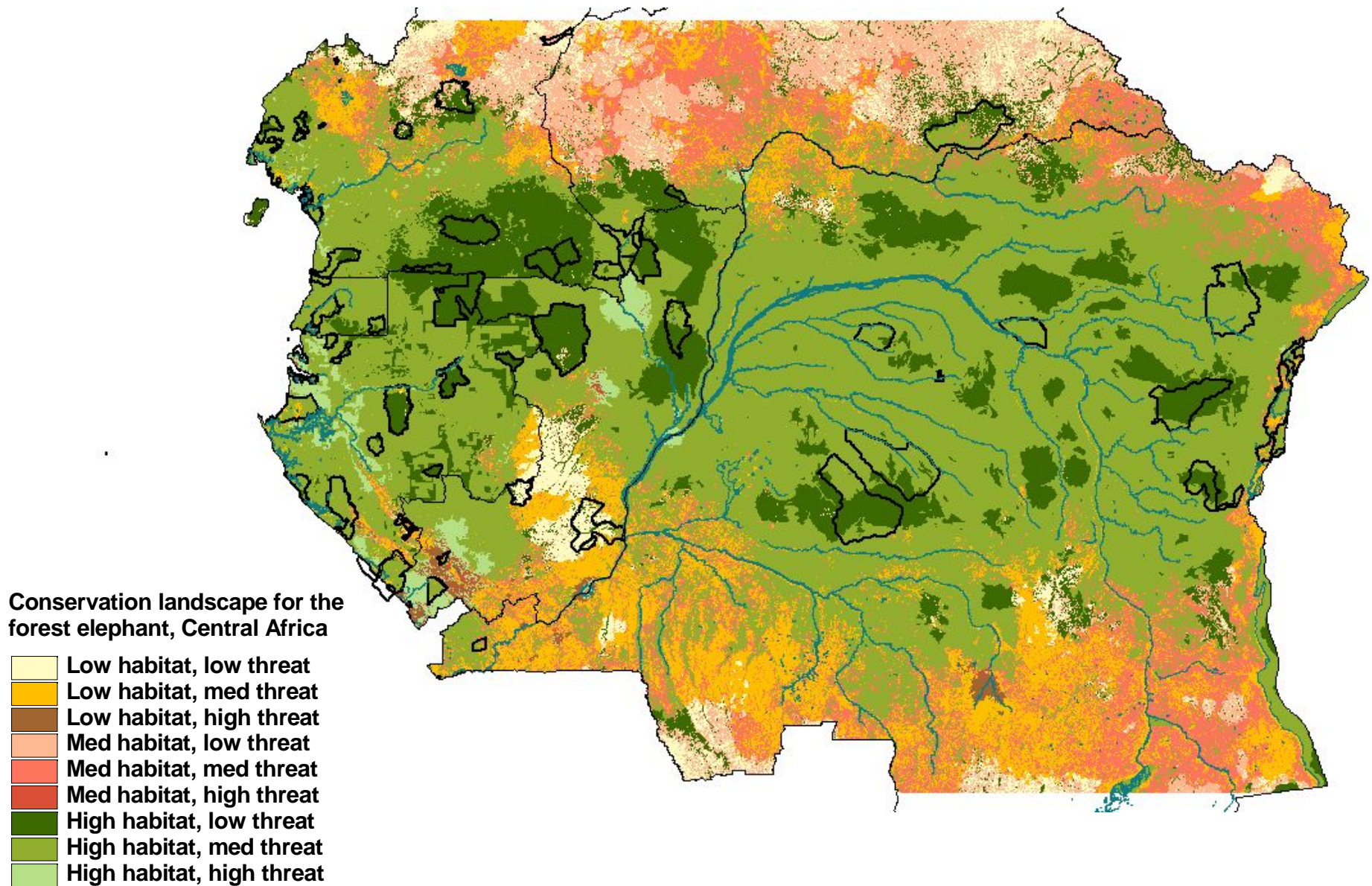
- Sanderson, E. W., M. Jaiteh, M. A. Levy, K. H. Redford, A. V. Wannebo, and G. Woolmer. 2002. The human footprint and the last of the wild. *Bioscience* 52:891-904.
- Senft, R. L. et al. 1987. "Large herbivore foraging and ecological hierarchies." *BioScience* 37:789-799.
- Strindberg, S., K. Didier, and F. Maisels. 2004. Appendix I: Preliminary Biological, Human & Conservation Landscapes for the Ndoki-Likouala Conservation Area. Wildlife Conservation Society (WCS) Internal Report. Unpublished. Living Landscapes Program. Bronx, NY.
- Thurrow, R. 2002. "Getting the scoop on these elephants is next to impossible. Ghanaians collect droppings to count elusive beasts; in 3 years, just 1 photo." *Wall Street Journal*, November 27: A-1, A-6.
- Trombulak, S. C., & Frissel, C.A. 2000. "Review of ecological effects of roads on terrestrial and aquatic communities." *Conservation Biology* 14:18-30
- Viljoen, P.J. 1989. "Spatial distribution and movements of elephants (*Loxodonta Africana*) in the northern Namib desert region of the Kaokoveld, South West Africa/Namibia." *J. Zool. Lond.* 219:19.
- Walker, P.A. 1990. "Modelling wildlife distributions using a geographic information system: kangaroos in relation to climate." *Journal of Biogeography* 17:279-289.
- Walsh, P.D., Abernethy, K. A., Bermejo, M., Beyersk, R., De Wachter, P., Akou, M. E., Huljbreigis, B., Mambounga, D. I., Toham AK, Kilbourn AM, Lahm SA, Latour S, Maisels F, Mbina C, Mihindou Y, Obiang SN, Effa EN, Starkey MP, Telfer P, Thibault M, Tutin, CEG, White LJT, Wilkie DS. 2003. "Catastrophic ape decline in western equatorial Africa." *Nature* 422: 611-614.
- Wildlife Conservation Society (WCS). 2005. "Building Biological and Threats Landscapes from ecological first principles, a step-by-step approach. Living Landscapes Program – Building Biological and Threats Landscapes." Living Landscapes Technical Manual 3. Bronx, NY:WCS.
- Wilkie D. S., Carpenter, J. F. and Zhang. 2001. "The under-financing of protected areas in the Congo Basin: So many parks and so little willingness-to-pay." *Biodiversity and Conservation* 10: 691 - 709.
- White, L.J.T., Tutin, C.E.G., Fernandez, M. 1993. "Group composition and diet of forest elephants, *Loxodonta Africana cyclotis* Marschie 1900, in the Lope Reserve, Gabon." *African Journal of Ecology* 31:181-199.
- White, L. J. T. 1994. "Biomass of Rain-Forest Mammals in the Lope Reserve, Gabon." *Journal of Animal Ecology* 63:499-512.

**Figure 1.** Collected forest elephant telemetry data in five sub-regions across the Congo Basin

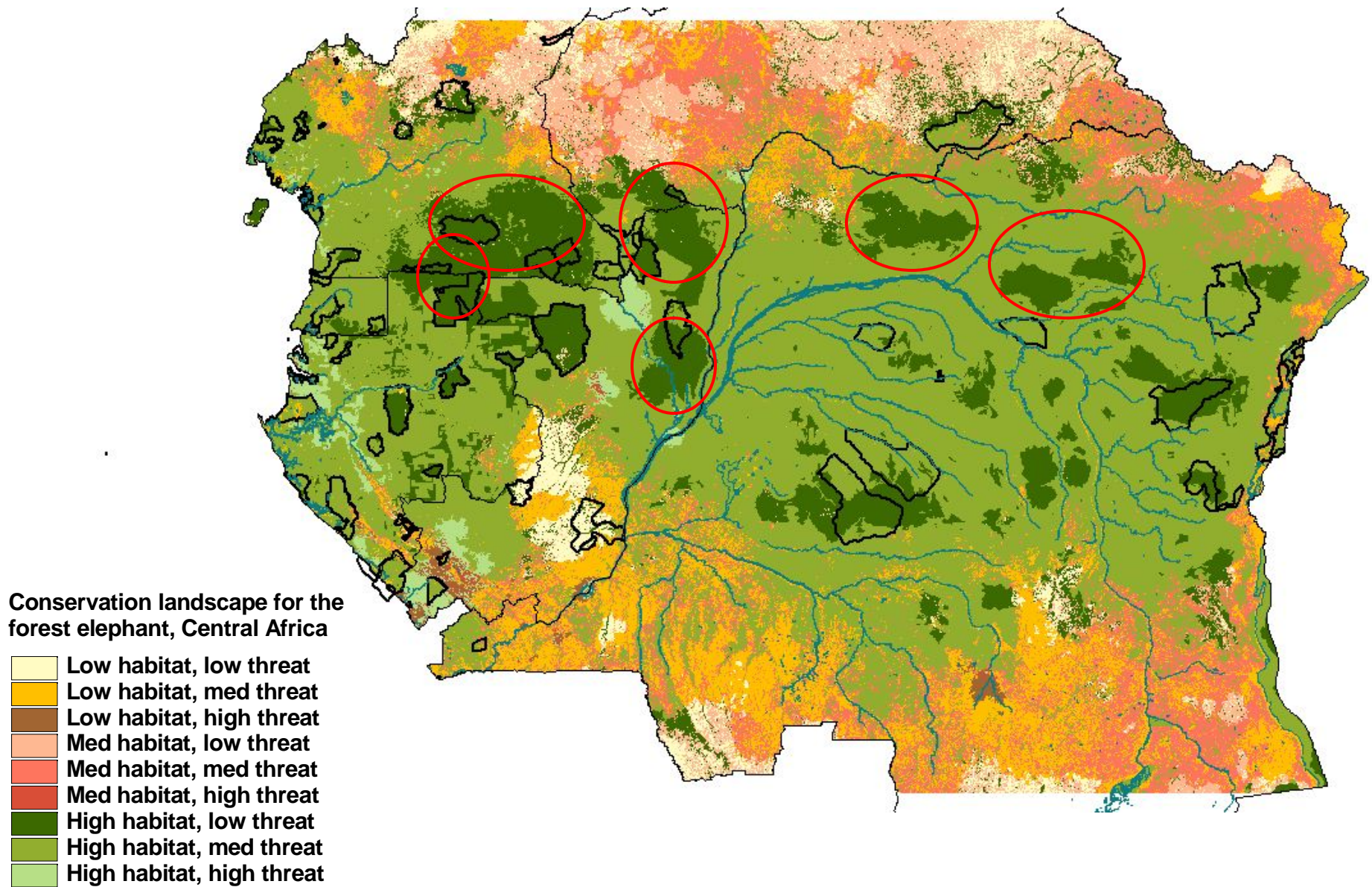


**Figure 2.** Conservation Landscape for the forest elephant in the Congo Basin

NOTE: Classes are categorical, not continuous. National Parks were not used as an input to the model but are displayed graphically.



**Figure 3.** Potential future priority areas for forest elephant conservation in the Congo Basin



**Table 1. Data used in GLM resource selection analysis**

<b>Covariate dataset</b>	<b>Geographic availability of data</b>	<b>Data Source</b>	<b>Method derived</b>
Landcover type	All sub-regions	South Dakota State and University of Maryland	MODIS 250m data
Mineral deposits (bais)	Only available for sub-regions 4 (Ivindo N.P.) and 5 (Sangha Tri-National N.P.)	Wildlife Conservation Society and CARPE	Digitized from a combination of Landsat ETM+ and ASTER data. Some bai locations in Sangha Tri-National have been previously field checked.
Rivers	All sub-regions	CARPE	
Slope	All sub-regions	NASA and USGS EROS Data Center	Percent rise derived from Shuttle Radar Topography Mission (SRTM) data.
Wetlands	All sub-regions	UNEP-WCMC's Biodiversity Map Library	
Roads	All sub-regions	<b>Subregions 1, 2, 3 (Gabon):</b> Wildlife Conservation Society. <b>Subregion 4 (R. of Congo):</b> World Resources Institute. <b>Subregion 5 (R. of Congo and Central African Republic):</b> World Resources Institute and CARPE.	Roads were digitized from a variety of high-resolution NASA satellite data products.
National Parks	All sub-regions	World Database of Protected Areas (IUCN-WCMC), CARPE and WCS	PAs derived from a combination of high-resolution satellite data products and paper maps.
National Park Headquarters	All sub-regions	Wildlife Conservation Society	Provided by country governments
Logging concessions	All sub-regions	<b>Gabon:</b> Wildlife Conservation Society. <b>Cameroon:</b> World Resources Institute. <b>R. of Congo:</b> World Resources Institute.	Provided by country governments.
Human settlements	All sub-regions	<b>Subregions 1, 2, 3 (Gabon):</b> Wildlife Conservation Society. <b>Subregion 4 (R. of Congo):</b> World Resources Institute. <b>Subregion 5 (R. of Congo and Central African Republic):</b> World Resources Institute and CARPE.	GTZ, and digitized from a variety of high-resolution NASA satellite data products.
Navigable Rivers	All sub-regions	CARPE	Designated by CARPE's "main rivers" file

**Table 2. Data used as input for Conservation Landscape model**

Factor Type	Covariate dataset	Geographic availability of data	Data Source	Method derived	Expected impact on elephant density and range
<b>1. Biological Factors</b>					
	Mature and degraded forest	Congo basin-wide	South Dakota State and University of Maryland	MODIS 250m data	Positive impact. Forest elephants depend on large tracts of intact forest for their habitat.
	Mineral deposits (bais)	Only available for areas including and between Ivindo N.P. and Sangha Tri-National N.P.	Wildlife Conservation Society and CARPE	Digitized from a combination of Landsat ETM+ and ASTER data. Some bai locations in Sangha Tri-National have been previously field checked.	Positive impact. Elephants are very attracted to areas rich in mineral deposits.
	Wetlands	Congo basin-wide	UNEP-WCMC's Biodiversity Map		Positive impact. Elephants are attracted to wetlands
<b>2. Human Factors</b>					
	Roads	Congo basin-wide	<b>Gabon:</b> Wildlife Conservation Society. <b>Cameroon:</b> World Resources Institute. <b>R. of Congo:</b> World Resources Institute. <b>Equatorial Guinea:</b> CARPE. <b>Central African Republic:</b> CARPE. <b>DRC:</b> Université Catholique de Louvain.	Roads were digitized from a variety of high-resolution NASA satellite data products.	Negative impact. For this analysis, only roads designated to represent known human threat (ie, used by humans as access points) were included.

	Logging concessions	Congo basin-wide, excluding DRC (logging concessions cancelled).	<b>Gabon:</b> Wildlife Conservation Society. <b>Cameroon:</b> World Resources Institute. <b>R. of Congo:</b> World Resources Institute.	Provided by country governments.	Negative impact. Areas being actively logged represent human threat to forest elephants
	Human settlements	Congo basin-wide	<b>Gabon:</b> Wildlife Conservation Society. <b>Cameroon:</b> World Resources Institute. <b>R. of Congo:</b> World Resources Institute. <b>Equatorial Guinea:</b> CARPE. <b>Central African Republic:</b> CARPE. <b>DRC:</b> DRC GIS Working Group.	GTZ, and digitized from a variety of high-resolution NASA satellite data products.	Negative impact.
	Navigable Rivers	Congo basin-wide	CARPE	Designated by CARPE's "main rivers" file	Negative impact. Navigable rivers represent axes of human access.
	Human refugee camps	Congo basin-wide	UNEP	Courtesy of Johannes Akiwumi, UNEP: <b>NOT DISTRIBUTABLE</b>	Negative impact.

**Table 3.** Response of significant ( $p$ -value < 0.05) covariates in each sub-region (%)

COVARIATES	Sub-region 1 (10 elephants)			Sub-region 2 (4 elephants)			Sub-region 3 (4 elephants)		
	% Significant	% Prefer	% Avoid	% Significant	% Prefer	% Avoid	% Significant	% Prefer	% Avoid
Bais	NA	NA	NA	NA	NA	NA	NA	NA	NA
Non-navigable rivers	70	43	57	75	67	33	75	100	0
Wetlands	70	86	14	NA	NA	NA	75	67	33
Slope	50	80	20	100	0	100	50	50	50
National Park headquarters	90	29	71	75	100	0	25	0	100
Navigable rivers (accessible by humans)	40	75	25	50	0	100	50	100	0
Roads	40	100	0	100	50	50	NA	NA	NA
Settlements	60	50	50	75	67	33	50	50	50
Logging concessions	NA	NA	NA	NA	NA	NA	75	75	25
Landcover 1 (Mature forest)	40	100	0	25	100	0	25	100	0
Landcover 2 (Woodland 41-60% tree cov)	NA	NA	NA	NA	NA	NA	NA	NA	NA
Landcover 4 (Grassland <10% tree cov)	20	100	0	100	100	0	NA	NA	NA

COVARIATES	Sub-region 4 (5 elephants)			Sub-region 5 (7 elephants)		
	% Significant	% Prefer	% Avoid	% Significant	% Prefer	% Avoid
Bais	80	50	50	86	50	50
Non-navigable rivers	100	60	40	86	67	33
Wetlands	40	0	100	71	60	40
Slope	60	33	67	43	100	0
National Park headquarters	40	100	0	57	25	75
Navigable rivers (accessible by humans)	NA	NA	NA	14	100	0
Roads	80	25	75	29	100	0
Settlements	60	67	33	29	50	50
Logging concessions	NA	NA	NA	43	100	0
Landcover 1 (Mature forest)	40	100	0	NA	NA	NA
Landcover 2 (Woodland 41-60% tree cov)	NA	NA	NA	NA	NA	NA
Landcover 4 (Grassland <10% tree cov)	NA	NA	NA	NA	NA	NA